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A few results from radiation transport tool comparison study at JPL

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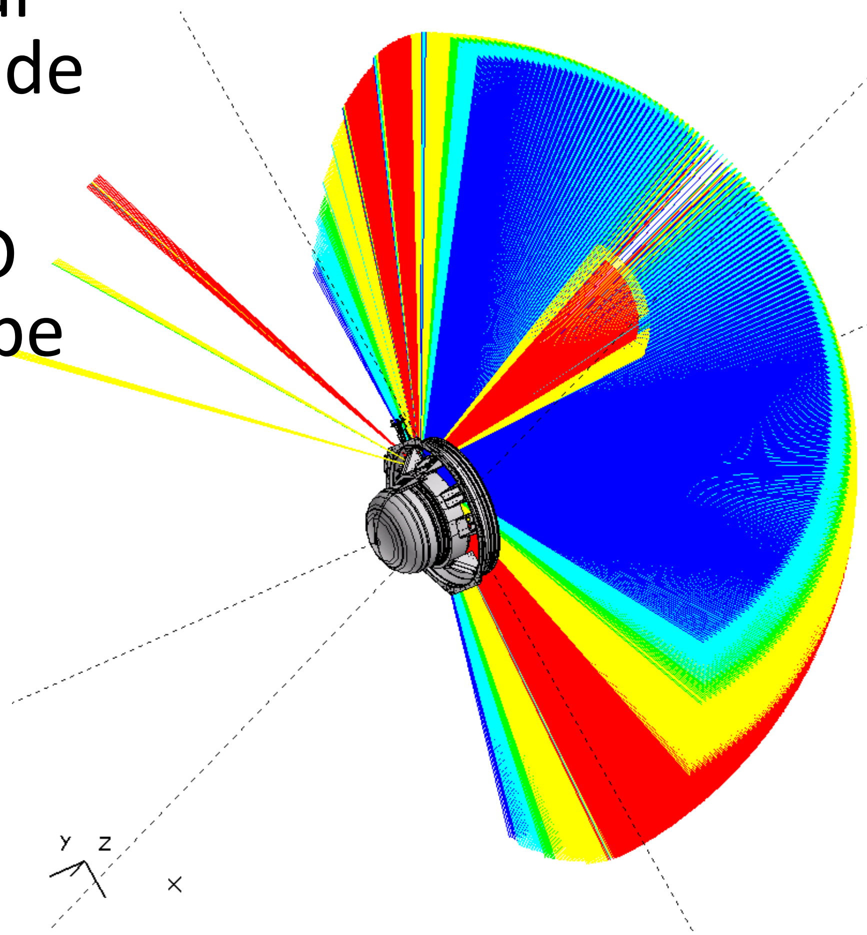
Topics

- Survey of radiation shielding tools
  - Introduction of widely used radiation shielding tools
  - Primary applications of radiation transport tools
- NOVICE vs. FASTRAD for TID
- NOVICE vs. MCNPX for Dose-Depth Curve
- Geant4 vs. MCNPX for Pulse-height Simulation in a Thin Silicon Layer

Ray Tracing Codes

- Ray tracing codes are useful to perform system level trade studies fast
- Ray-tracing codes with CAD interface capability would be very useful
- Tools available:
  - FASTRAD: http://trad.fr/
  - MEVDP: http://www-rsicc.ornl.gov/
  - “SIGMA” option in Novice: tj@empc.com



Transport Codes – Species

- Transport codes model actual particle interactions in the material (Ray tracing codes do not)
- It is important to model all particle species when performing transport analyses
  - Electrons
  - Photons
  - Protons
  - Neutrons
  - Heavy Ions
- Each transport code considers only a specific set of particles

Radiation transport analyses will be required to cover a wide range of particle species

Commonly Available Radiation Transport Codes

	Electron	Photon	Proton	Neutron	Heavy Ion
CREME96 creme96.nrl.navy.mil			O		O
TRIM www.srim.org			O		O
ITS3.0 www-rsicc.ornl.gov	O	O			
NOVICE tj@empc.com	O	O	O		O
MCNP(X) mcnpx.lanl.gov	O	O	O	O	O
Geant4 geant4.web.cern.ch/geant4/	O	O	O	O	O

Other radiation transport codes are available: EGS4, CEPXS, HZETRN, PHITS, PENELOPE, FLUKA, MARS, etc.

Transport Codes – Applications

- Transport codes are needed to consider the following
  - Total ionizing dose
  - Displacement damage dose
  - Single event effects
  - Internal charging
  - Secondary particle environment behind shield
- Transport codes can be used for particle detector simulation

Radiation transport analyses are used to cover a wide range of radiation effects

Features of Common Transport Codes

Code	Primary Application	Comments
CREME96	Heavy Ion LET Spectra	Limited to spherical shell aluminum shielding
TRIM	Proton or heavy ion beam simulation	1-dimensional Only Coulomb interaction
ITS3.0 (TIGER)	Electron or photon beam simulation for dose and charging rate profiles	Excellent electron/photon physics Extensively benchmarked
NOVICE	Spacecraft level shielding analysis	"Adjoint" (fast for space environment application) No secondary neutrons Not accurate for secondary electrons
MCNP(X)	Full 3-D detector/sensor simulation Transients calculation	Good physics and extensive development history Slow for space application
Geant4	Full 3-D detector/sensor simulation Transients calculation	Good physics Many Geant4-based "tools" are available Slow for space application

Comments are based on current JPL experience

FASTRAD - NOVICE

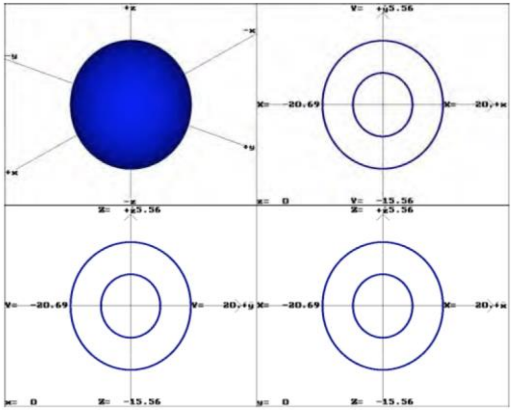
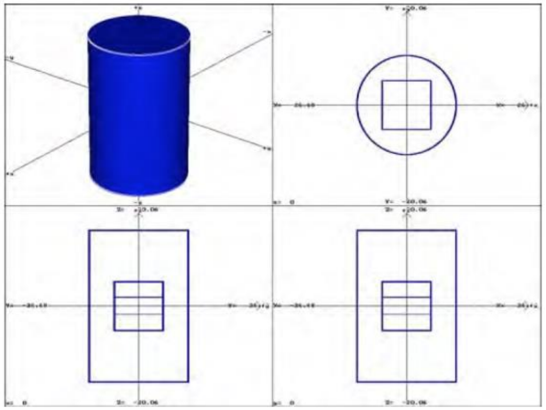


Figure 1. A Spherical Shell in a Spherical shell Container

Table 1. Dose Comparison for a Configuration of Spherical Shell in Spherical Shell Container

3D Mass Model	Computer Code	Ionizing Dose (krad, Si) [RDF = 1]			
Simple 3D Geometry (A spherical shell in a spherical shell container)		Electron	Photon	Proton	**Total**
• Inner Shell (**Aluminum**, 2.5 mm) • Outer Shell (**Aluminum**, 2.5 mm)	FASTRAD	277.80	2.03	8.91	288.7
	NOVICE	273.0	2.01	8.90	283.9
• Inner Shell (**Tantalum**, 2.5 mm) • Outer Shell (**Aluminum**, 2.5 mm)	FASTRAD	87.03	3.49	0.99	91.5
	NOVICE	41.90	6.86	2.04	50.8
• Inner Shell (**Tantalum**, 2.5 mm) • Outer Shell (**Tantalum**, 2.5 mm)	FASTRAD	36.39	3.93	0.41	40.7
	NOVICE	8.45	7.27	0.96	16.7



A Box Containing Two Boards in a Cylindrical Container

Table 2. Dose Comparison for a Configuration of Box in Cylindrical Container

3D Mass Model	**Computer Code**	**Ionizing Dose** (krad, Si) [RDF = 1]			
Simple 3D Geometry (A Box with 2 boards in a Cylindrical Container)		Electron	Photon	Proton	**Total**
• Box Wall (**Aluminum**, 2.5 mm) • 2 PCB (**Aluminum**, 1.5 mm) • Container Wall (**Aluminum**, 2.5 mm)	FASTRAD	200.94	2.45	4.63	208.0
	NOVICE	210.0	2.50	4.72	217.2
• Box Wall (**Tantalum**, 2.5 mm) • 2 PCB (**Aluminum**, 1.5 mm) • Container Wall (**Aluminum**, 2.5 mm)	FASTRAD	60.08	3.74	0.66	64.5
	NOVICE	33.8	6.74	1.33	41.9
• Box Wall (**Tantalum**, 2.5 mm) • 2 PCB (**Tantalum**, 1.5 mm) • Container Wall (**Tantalum**, 2.5 mm)	FASTRAD	16.02	3.80	0.23	20.1
	NOVICE	3.19	6.25	0.51	10.0

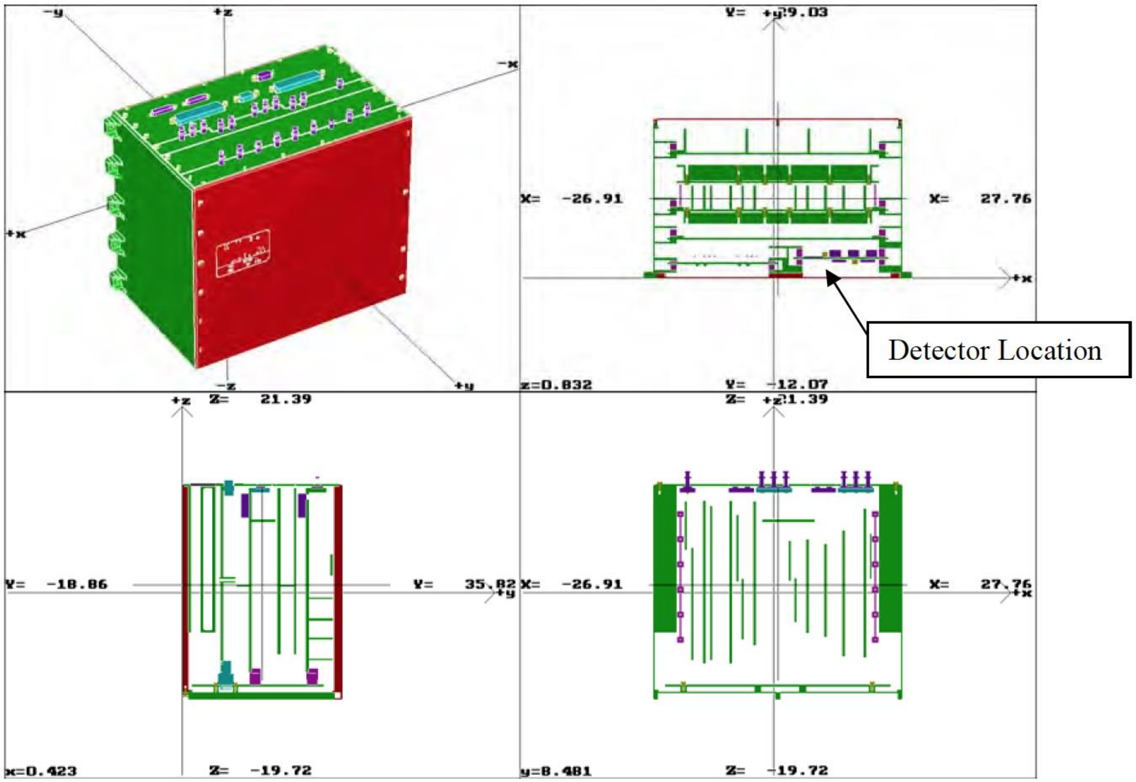
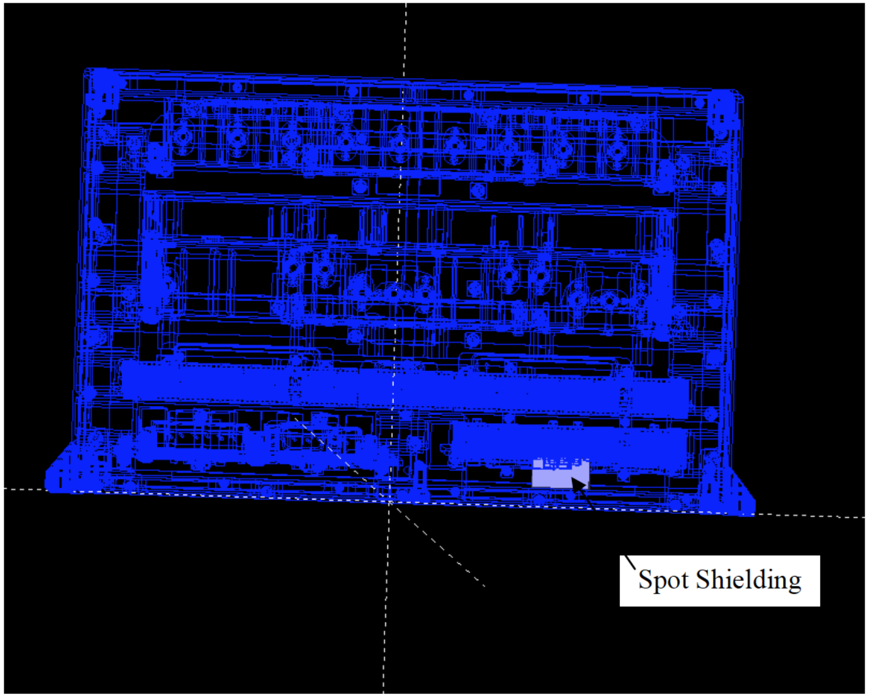


Table 3. Dose Comparison for an Electronics Box CAD Model

3D Mass Model	Computer Code	Ionizing Dose (krad, Si) [RDF = 1]			
Electronics Box CAD Model		Electron	Photon	Proton	**Total**
• Entire Electronics Box (**Aluminum**)	FASTRAD	365.6	2.69	13.4	381.7
	NOVICE	356	2.93	13.4	372.3
• Entire Electronics Box (**Tantalum**)	FASTRAD	60.02	2.48	1.10	63.6
	NOVICE	54.8	4.29	3.01	62.1



(A picture generated by FASTRAD)

Figure 4. Spot Shielding in Electronics Box CAD Model

Table 4. Dose Comparison for Spot Shielding Inserted in Electronics Box CAD Model

3D Mass Model	**Computer Code**	**Ionizing Dose** (krad, Si) [RDF = 1]			
Electronics Box with a manually inserted spot shielding		Electron	Photon	Proton	**Total**
• Entire Electronics Box (**Aluminum**) • Spot Shielding (**Aluminum**, 4.8 mm thick box wall)	FASTRAD	96.88	3.26	1.78	101.9
	NOVICE	111.0	3.49	1.8	116.3
• Entire Electronics Box (**Aluminum**) • Spot Shielding (**Tungsten**, 4.8 mm thick box wall)	FASTRAD	8.10	3.54	0.15	11.8
	NOVICE	1.96	4.41	0.30	5.67

Summary for NOVICE vs. FASTRAD

- Based on the above calculations and comparisons, FASTRAD is considered a conservative radiation dose estimation tool. Its built-in ray tracing function can generate dose estimate in a very short period of time. Its fast calculation capability significantly outpaces the more sophisticated NOVICE code when complex CAD model was involved. Its real-time visualization capability provides radiation engineers the tool to easily select parts location and perform optimum shielding design and analysis by moving components or adding shielding in the existing CAD file.

- After the “preliminary” radiation dose estimates are done, NOVICE code could be used to calculate the more precise radiation dose values when the hardware design is “finalized”.

NOVICE – MCNPX

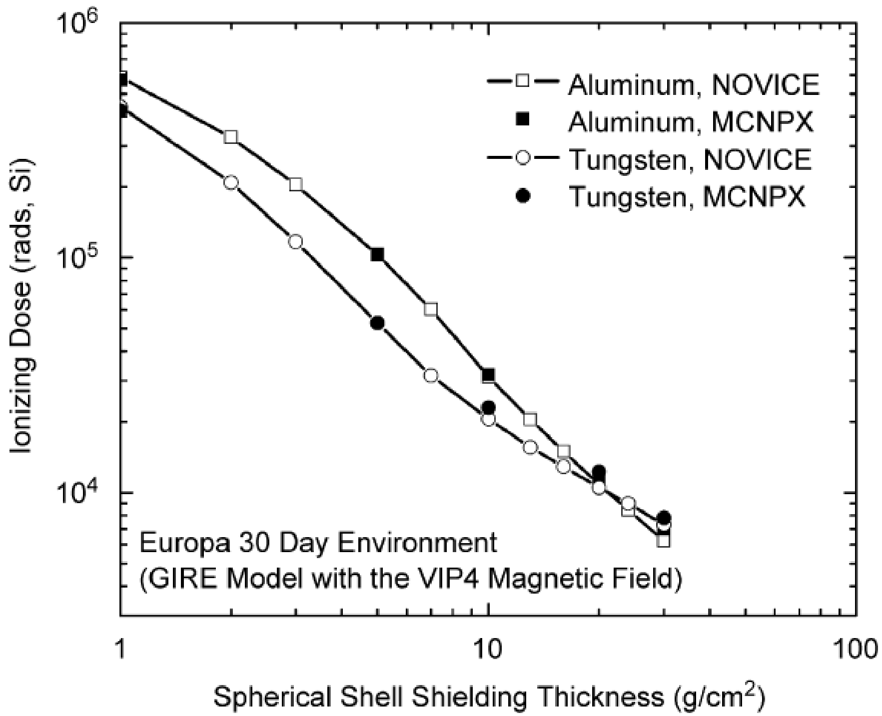


Fig. 2. Ionizing doses calculated for a detector located at the center of spherical shell shielding of aluminum and tungsten in a 30-day Europa mission with NOVICE and MCNPX, respectively. (100 rad = 1 Gray).

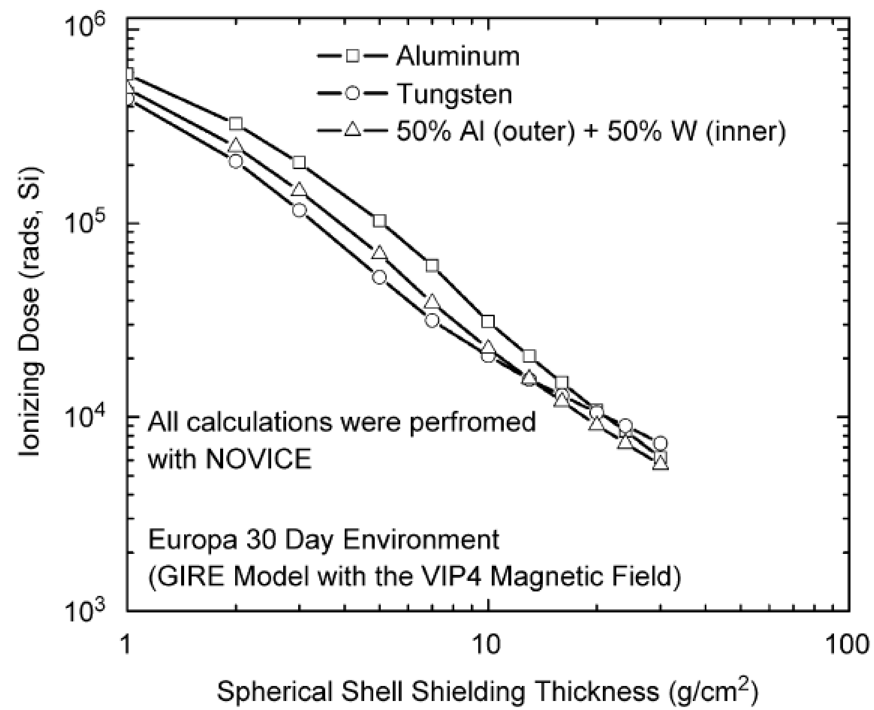


Fig. 3. Ionizing doses calculated with NOVICE for a detector located at the center of the spherical shell shielding of aluminum, tungsten, and 50% areal mass aluminum (outer layer)/50% areal mass tungsten (inner layer) combination in a 30-day Europa mission. (100 rad = 1 Gray).

Cherng et al., NIMA 2007

MCNPX – GEANT4

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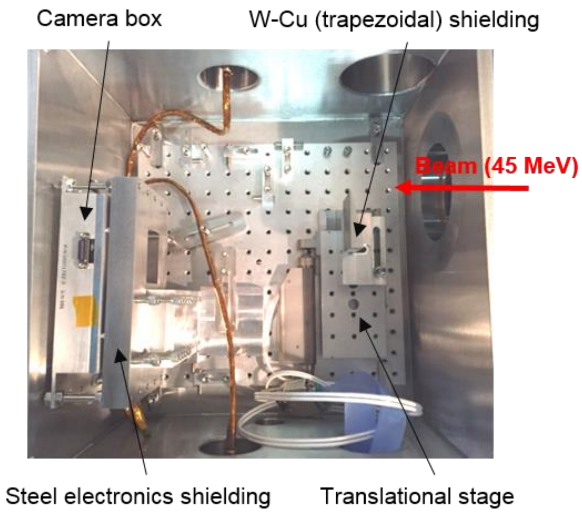
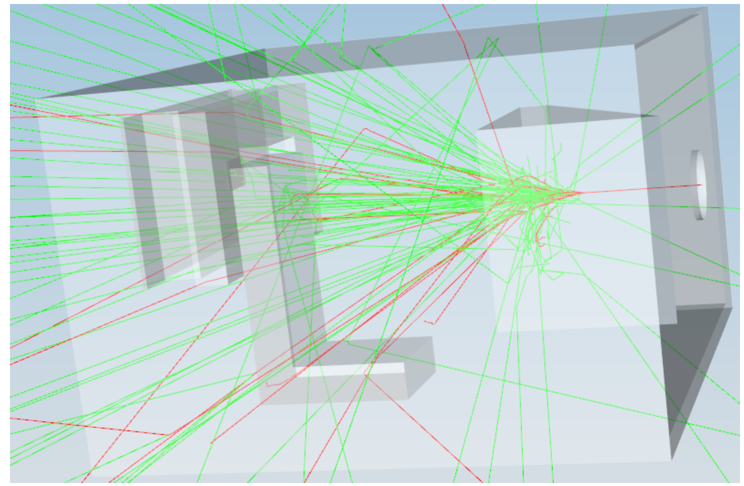
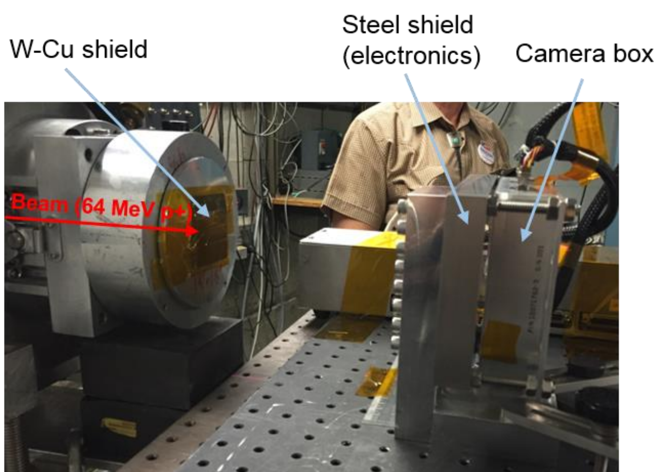
Firefly Beam-Line Tests of Detector

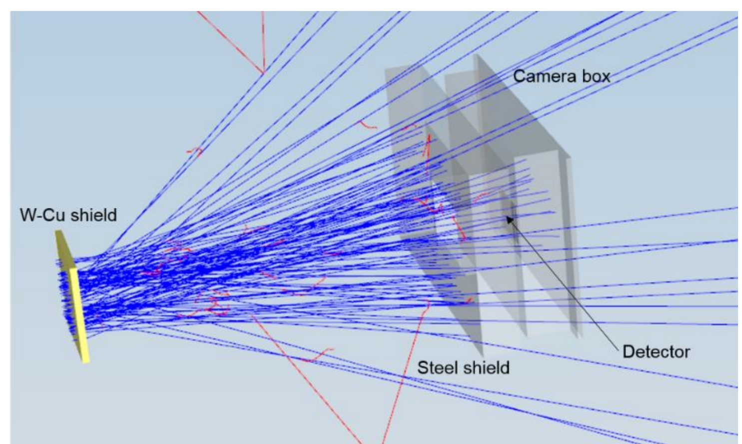
BNL Electron Beam-Line Tests and Simulations

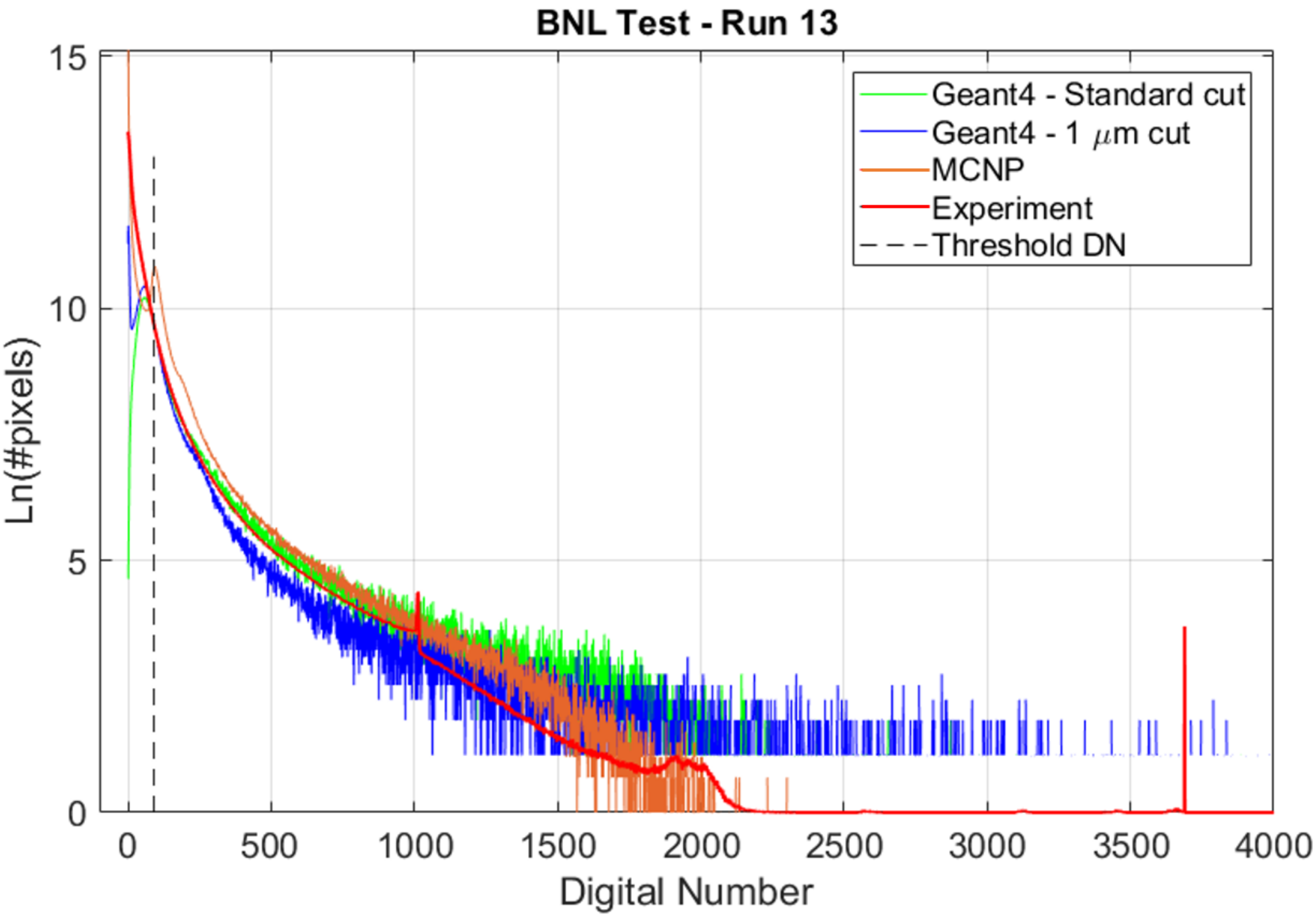




UC Davis Proton Beam-Line Tests and Simulations






BNL Test - Run 13
Geant4 - Standard cut
Geant4 - 1 μm cut
MCNP
Experiment
Threshold DN
Ln(#pixels)
Digital Number
0
5
10
15
0
500
1000
1500
2000
2500
3000
3500
4000

Summary

- Radiation transport codes are needed to:
  - Estimate doses and other radiation effects
  - Design radiation shield
  - Understand instrument's response to radiation
- Different codes should be used for different applications and for different radiation type
- Benchmark study (including beam testing) is recommended to validate simulation results for specific hardware application
  - This is especially true for science instrument simulations

THANK YOU!

QUESTIONS?